The Arithmetic of Color Depth

Resolution isn't the only factor governing the quality of your images. Equally important is the number of colors in the image. When you view a natural scene, or a well done photographic color print, you are able to differentiate millions of colors. Digital images can approximate this color realism, but whether they do so on your system depends on its capabilities and its settings. How many colors there are in an image, or how many a system can display is referred to as color depth, pixel-depth, or bit depth. Older PCs are stuck with displays that show only 16 or 256 colors. However, almost all newer systems include a video card and a monitor that can display what's called 24-bit True Color. It's called true color because these systems display 16 million colors, about the number the human eye can discern.

TIP: Checking Your System

You may have to set your system to full-color, it doesn't happen automatically. To see if your Windows system supports True Color (not all do), display Window's Start menu, point to Settings to cascade the menu, and then click Control Panel. When the Control panel opens, double-click the Display icon or command to display the Display Properties dialog box, then click the Settings tab on the dialog box and check the Color palette setting.

How do bits and colors relate to one another? It's simple arithmetic. To calculate how many different colors can be captured or displayed, simply raise the number 2 to the power of the number of bits used to record or display the image. For example, 8-bits gives you 256 colors because $2^8=256$. Here's a table to show you some other possibilities.

Name	Bits per pixel	Formula	Number of colors
Black and white	**1**	2^1	**2**
Windows display	**4**	2^4	**16**
Gray scale	**8**	2^8	**256**
256 color	**8**	2^8	**256**
High color	**16**	2^{16}	**65 thousand**
True color	**24**	2^{24}	**16 million**

Black and white images require only 2-bits to indicate which pixels are white and which are black. Gray scale images need 8 bits to display 256 different shades of gray. Color images are displayed using 4 bits (16 colors), 8 bits (256 colors), 16 bits (65 thousand colors) called high color,

and 24 bits (16 million colors) called true color. Some cameras and scanners will use 30 or 36 bits per pixel. These extra bits are used to improve the color in the image as it is processed down to its 24-bit final form. (**Ed note**: Are there any 30/36 bit monitors or printers?)

Review: Bits and Bytes

When reading about digital systems, you frequently encounter the terms bit and byte.

The bit is the smallest digital unit. It's basically a single element in the computer that like a light bulb has only two possible states, on (indicating 1) or off (indicating 0). The term bit is a contraction of the more descriptive phrase binary digit.

Bytes are groups of 8-bits linked together for processing. Since each of the eight bits has two states (on or off), the total amount of information that can be conveyed is 2^8 (2 raised to the 8th power), or 256 possible combinations.

Exploring Color Depth

This figure and Part 4 on the Excel worksheet "Image Size Calculator" calculate the total number of pixels in an image when you enter the images width and height in pixels.

4. Color Depth and File Sizes

1	**Bits per pixel**	24	
2	**Number of possible colors**	16,777,216	
3	**Image width**	1,600	pixels
4	**Image height**	1,200	pixels
5	**Total number of pixels**	1,920,000	pixels
6	**File size (uncompressed)**	46,080,000	bits
		5,760,000	bytes
		5,760.00	kilobytes
		5.76	megabytes
7	**Table of color depths**		

Name	Bits per pixel
Black and white	1
Windows display	4
Gray scale or 256 colors	8
High color	16
True color	24
Oversampled	30

1. Enter any bits per pixel from the table of color depths (on line 7 and following) on this line.

2. A formula on this line calculates the number of possible colors by raising the number 2 to number of bits per pixel.

3. Enter the width of the digital image in pixels on this line.

4. Enter the height of the digital image in pixels on this line.

5. A formula on this line calculates the total number of pixels in the image by multiplying the image's width by its height.

6. A formula on this line calculates the size of the uncompressed file that would be needed to store the image of the size and color depth you've entered. File sizes are shown in bytes, kilobytes, and megabytes.

The Arithmetic of Displaying Images

When a digital image is displayed on the computer screen, its size is determined by three factors—the screen's resolution, the screen's size, and the number of pixels in the image.

Excel Worksheet

The calculations described in this section are nothing more than subtraction, addition, multiplication, and division. However, to make it easier to explore the various relationships being discussed, you can download an Excel worksheet "Image Size Calculator" that will help you better follow the discussion and explore the concepts we discuss. The worksheet has been saved in Excel 5 format so that version and all later versions can read it. To download the unzipped version (20 Kilobytes), click here.

The Screen's Resolution

The size of each pixel on the screen is determined by the resolution of the screen. The resolution is almost always given as a pair of numbers that indicate the screen's width and height in pixels. For example, a monitor may be specified as being a low-resolution 640 x 480, a medium resolution of 800 x 600, or a high-resolution of 1024 x 768 or more. (The first number in the pair is the number of pixels across the screen. The second number is the number of rows of pixels down the screen.)

This is a 640 x 480 display. That means there are 640 pixels on each row and there are 480 rows.

Another way to think about the size of each pixel is in terms of how many pixels are displayed per inch on the screen. The larger the pixels, the fewer fit per inch. As you can see from the illustration below, the actual number of pixels per inch (the numbers in red) depends on both the resolution and the size of the monitor. (Screen measurements are based on a diagonal, and these measurements are horizontal measurements across the screen so they don't relate exactly to screen sizes.)

	Monitor Size				
Resolution	14	15	17	19	21
640 x 480	60	57	51	44	41
800 x 600	74	71	64	56	51
1024 x 768	95	91	82	71	65

The red numbers in the illustration are the pixels per inch for each combination of monitor size and resolution. To simplify the calculations, images that are to be displayed on the screen are generally considered to be displayed at 72 pixels per inch (ppi). As you can see from the table, 72ppi isn't an exact number for any resolution on any screen, but it tends to be a good compromise. (The 72 dpi is held over from an early era in Apple's history.)

Screen Resolution and Image Size

On any given monitor, changing screen resolution changes the size of displayed objects such as icons, text, buttons, and images. As the resolution increases, object sizes decrease but they do appear sharper. Take a look here at the same image displayed at three different resolutions: 640 x 480, 600 x 800, and 1024 x 768.

640 x 480. At this resolution, an image in Photoshop fills the screen.

800 x 600. When the screen resolution is increased, the image gets smaller.

1024 x 768. When the resolution is increased again, the image gets even smaller.

When displaying images on the screen, it's important that the viewer be able to see the entire image without having to scroll it. To ensure this, Web designers often assume that the lowest common denominator display is a 640 x 480 screen. For this reason, most images to be sent by e-mail or posted on a screen are sized so they are no larger than 600 pixels wide (for landscape images) or 400 pixels high (for portrait images).

TIP: Checking Your System

To see what resolution your Windows system is set to, display Window's Start menu, point to Settings to cascade the menu, and then click Control Panel. When the Control panel opens, double-click the Display icon or command to display the Display Properties dialog box, then click the Settings tab on the dialog box and check the Screen Area setting.

Screen Size and Image Size

Just as the screen's resolution can affect the size of an image, so can the size of the display. If you have a 14" monitor and 21" both set to 800 x 600 pixels, the pixels per inch are different. The same 800 pixels are

spread across a larger screen on the larger monitor so the pixels per inch falls. Imagine the image printed on a balloon. As you inflate it, the image gets larger.

Exploring Display Sizes

This figure and Part 2 on the Excel worksheet "Image Size Calculator" calculate the size of an image displayed on the screen.

2. Displaying Images			
1	Width of digital image	800	pixels
2	Height of digital image	480	pixels
3	Measured width of screen	14	inches
4	Screen's horizontal resolution	800	pixels
5	Screen's ppi	57	ppi
6	Width of image on screen	14	inches
7	Height of image on screen	8	inches
8	Will image fit on screen?	YES	

1. Enter the width of the image in pixels on this line.

2. Enter the height of the image in pixels on this line.

3. Measure the width of the screen display and enter it on this line.

4. Enter the horizontal resolution your screen is set to on this line. (For example, if it's set to 800 x 600, enter 800.)

5. A formula on this line calculates you screen's actual dots-per-inch by dividing it's horizontal resolution in pixels by its width in inches. In the illustration above it divides 800 by 14 for a ppi of 57.

6. A formula on this line calculates the width of the image on the screen in inches by dividing the width in pixels by the screen's ppi. In the illustration above it divides 800 by 57 for an image width of 14 inches.

7. A formula on this line calculates the height of the image in inches by dividing the height in pixels by the screen's ppi.

8. A formula on this line compares the width of the image in pixels, with the screen's horizontal resolution. If the image is smaller than the screen (in pixels), it will fit, otherwise it won't.

The Arithmetic of Image Sizes

Let's start with one surprising fact: A pixel has no size or shape. At the time it's born, it's simply an electrical charge much like the static electricity that builds up on your body as you shuffle across a carpet on a dry day. A pixel is only given size and shape by the device you use to

display or print it. Understanding how pixels and image sizes relate to one another takes a little effort but you need to bring nothing more to the process than your curiosity and elementary school arithmetic skills.

Excel Worksheet

The calculations described in this section are nothing more than subtraction, addition, multiplication, and division. However, to make it easier to explore the various relationships being discussed, you can download an Excel worksheet "Image Size Calculator" that will help you better follow the discussion and explore the concepts we discuss. The worksheet has been saved in Excel 5 format so that version and all later versions can read it. To download the unzipped version (20 Kilobytes), click here.

A pixel begins its life on the camera's image sensor during that flickering moment when the shutter is open. The size of each photosite on the image sensor can be measured, but the pixels themselves are just electrical charges converted into digital numbers. These numbers, just like any other numbers that run through your head, have no physical size.

Although the captured pixels have no physical dimensions, a sensor's size is specified like those in a digital photo, except the count is the number of photosites that it has on its surface. This size is usually specified in one of two ways—by the sensor's dimension in pixels, or by its total number of pixels. For example, the same image can be said to have 1800 x 1600 pixels (where "x" is pronounced "by" as in "1800 by 1600"), or to contain 2.88-million pixels (1800 multiplied by 1600).

This digital image of a Monarch butterfly chrysalis is 1800 pixels wide and 1600 pixels tall. It's said to be 1800x1600.

Since pixels stored in an image file have no physical size or shape, it's not surprising that the number of photosites doesn't by itself indicate a captured image's sharpness or size. This is because the size of each captured pixel, and the image of which it's a part, is determined by the

output device. The device can spread the available pixels over a small or large area on the screen or printout.

- If the pixels in an image are squeezed into a smaller area, perceived sharpness increases (from the same viewing distance). Images on high-resolution screens and printouts look sharper only because the available pixels are grouped into a small area—not because there are more pixels.
- As pixels are enlarged so the image is spread over a larger area, the image's perceived sharpness falls (from the same viewing distance). If enlarged past a certain point, the square pixels will begin to show —the image becomes pixilated.

To visualize this concept, imagine two tile mosaics, one with small tiles and one with large. The one with small tiles will have sharper curves and more detail. However, if you have the same number of large and small tiles, the area covered by the small tiles will be much less. Sharpness and detail is also related to viewing distance. If you stand close to the small mosaic it will appear almost identical to the larger one viewed from farther away.

SMALL MOSAIC IMAGE NEEDED LARGE MOSAIC IMAGE NEEDED

To make an image larger or smaller for a given output device, it must be resized (resampled) in the camera, in a photo-editing program, or by the application you're printing it with. Resizing is performed by interpolation, and sometimes this is done without your even being aware of it. When an image is made larger, extra pixels are added and the color of each new pixel is determined by the colors of its neighbors. When an image is made smaller, some pixels are deleted.

Exploring Image Sizes

This figure and Part 1 on the Excel worksheet "Image Size Calculator" calculate the total number of pixels in an image when you enter the image's width and height in pixels.

1. Image Sizes			
1	Width of image	1,600	pixels
2	Height of Image	1,200	pixels
3	Total pixels in image	1,920,000	pixels

1. Enter the width of the image in pixels on this line.

2. Enter the height of the image in pixels on this line.

3. A formula on this line calculates the total number of pixels in the image by multiplying the image's width by its height.

Exercise

Enter the width and height of your own images and see what the total number of pixels is. You can find image sizes in your camera's user guide. There may be more than one resolution, and if so, try them all.

The FinePix 4700 ZOOM records JPEG images at three compression image sizes. How many pixels are there in each image size?

- 2,400 x 1,800
- 1280 x 960
- 640 x 480

The Arithmetic of Scanning Film and Prints

Color scanners work by creating separate red, green, and blue versions of the image, and then merging them together to create the final digital image. Some scan all of the colors in one pass while others take three passes, a slower but higher quality method. Which method is used depends on the scanner's image sensor. Most scanners use linear CCDs arranged in a row. Those that require three passes use a single row of photosites and pass different filters (red, green, or blue) in front of the sensor for each pass or use three different light sources. Others have 3 rows of photosites, each row with its own filter so they can capture all three colors on a single pass.

Excel Worksheet

The calculations described in this section are nothing more than subtraction, addition, multiplication, and division. However, to make it easier to explore the various relationships being discussed, you can download an Excel worksheet "Scanning Calculator" that will help you better follow the discussion and explore the concepts we discuss. The worksheet has been saved in Excel 5 format so that version and all later versions can read it. To download the unzipped version (21 Kilobytes), click here.

As the image is scanned, a light source travels down the photo (some print and document scanners instead move the document past the light source). The light source reflects off a print or passes through a transparency and is focused onto the image sensor by a mirror and lens system. Because of this mirror and lens system, the sensor does not have to be as wide as the area being scanned.

The horizontal optical resolution of the scanner is determined by the number of photosites on its sensor. However, the vertical resolution is determined by the distance the paper or light source advances between

scans. For example, a scanner with a resolution of 600 x 1200 has 600 photosites on its sensor and moves 1/1200 of an inch between each scan.

Scanning and File Sizes

When scanning, your goal is to get a digital image file that contains all of the detail you need without the file being too large to work with. If you scan at too low a resolution, you'll lose detail. If you scan too high, you're file will be too large. When you scan an original image—either a slide or a print—the file size depends on a number of factors including the area being scanned, the resolution of the scanner, and the color depth, or number of bits assigned to each pixel. Let's take a look at this step-by-step as you'd calculate file sizes using the downloadable scanning calculator—Part 1.

1. Scanning and Files Sizes				
1	**Size of Original**	Horizontal	10.00	inches
2	(in inches)	Vertical	8.00	inches
3	**Scanner's Resolution**		300	dpi
4	**Scanned Pixels**	Horizontal	3,000	pixels
5		Vertical	2,400	pixels
6		Total	7,200,000	pixels
7	**Color Depth**		24	bits
8	**File Size**	Bits	172,800,000	bits
9		Bytes	21,600,000	bytes
10		Kilobytes	21,600	kilobytes
11		Megabytes	21.60	megabytes

1. Enter the width in inches of the art to be scanned.
2. Enter the depth or height of the art to be scanned.
3. Enter the scanner's optical resolution or the resolution to intend to scan at.
4. The scanned pixels horizontally are calculated by multiplying the scanner's resolution (line 3) times the horizontal size of the original (line 1).
5. The scanned pixels vertically are calculated by multiplying the scanner's resolution (line 3) times the vertical size of the original (line 2).
6. The total scanned pixels is calculate by multiplying the horizontal scanned pixels (line 4) times the vertical scanned pixels (line 5).
7. The color depth is where you enter the number of bits assigned to each pixel. This would usually be 1 if the image is black & while, 8 if it's grayscale (like a black and white photography), or 24 if it's color.
8. The file size in bits is calculated by multiplying the number of pixels in the image (line 6) time the color depth (line 7).

9. The file size in bytes is calculated by dividing the file size in bits (line 8) by 8.
10. The file size in kilobytes is calculated by dividing the file size in bytes (line 9) by 1,000.
11. The file size in megabytes is calculated by dividing the file size in kilobytes (line 10) by 1,000.

Scanning an Image for Printing at a Specified Size

There are times when you know what size you want a print to be and need to calculate backwards to what size the image file should be. For most purposes, you can expect to get photorealistic quality with a print having about 300 dpi. This means, a 4 x 6 print needs an image file of 1200 x 1800, and an 8 x 10 print needs one 2400 x 3000.

You can stretch or shrink images you've imported into programs such as PageMaker and QuarkXPress. Because the number of pixels in the image don't change, the dots per inch have to. For example, let's say you placed an 800x600 image on a page and it was 2-inches wide. If you print it out at that size, it will print at 400 dpi (800 divided by 2"). If you now stretch the image to be 4 inches wide, the dpi drops to 200 (800 divided by 4"). If you want the image 4" wide AND 400 dpi, best scan it so it's 1600 pixels wide before you import it. However, if it's to be printed on a printing press, the rules change and become more complex. You should scan the image so its sots per inch are twice the lines per inch (lpi) at which it will be printed.

2. Scanning an Image for Printing at a Specified Size				
1	**Size of Output**	Horizontal	12.00	inches
2	(in inches)	Vertical	8.00	inches
3	**Output Resolution (inches)**		300	dpi
4	**Size of Original**	Horizontal	3,600	pixels
5		Vertical	2,400	pixels
6	**Color Depth**		24	bits
7	**File Size**	Bits	207,360,000	bits
8		Bytes	25,920,000	bytes
9		Kilobytes	25,920	kilobytes
10		Megabytes	25.92	megabytes

1. Enter the width in inches of the art to be scanned.
2. Enter the depth or height of the art to be scanned.
3. Enter one of the the printer's output resolution in dots per inch (dpi).
4. The horizontal size of the original is calculated by multiplying the desired horizontal size of the output (line 1) by the desired output resolution (line 3).

5. The vertical size of the original is calculated by multiplying the desired vertical size of the output (line 2) by the desired output resolution (line 3).
6. Enter the color depth of the image. This would usually be 1 if the image is black & while, 8 if it's grayscale (like a black and white photography), or 24 if it's color.
7. The file size in bits is calculated by multiplying the horizontal by the vertical size of the original (lines 4 and 5) to calculate the total number of pixels in the image and then multiplying those by the color depth (line 6).
8. The file size in bytes is calculated by dividing the file size in bits (line 7) by 8.
9. The file size in kilobytes is calculated by dividing the file size in bytes (line 8) by 1,000.
10. The file size in megabytes is calculated by dividing the file size in kilobytes (line 9) by 1,000.

Scanning an Image for Screen Display

Scanning an image for the screen is the same as scanning one for printing except the output is usually specified in pixels, not inches. Although the actual number of pixels per inch on a monitor vary depending on its size and resolution, images are generally scanned at 72 ppi for screen display (although they are sometimes scanned up to 96 ppi). Making them any larger doesn't add any information to the image and just makes the files larger.

3. Scanning an Image for Screen Display				
1	**Image Being Scanned**	Horizontal	1.00	inches
2	(in inches)	Vertical	1.50	inches
3	**Screen's Resolution**		72	dpi
4	**Desired Image Width**		400	pixels
5	**Desired Image Height**		600	pixels
6	**Color Depth**		24	bits
7	**File Size**	Bits	5,760,000	bits
8		Bytes	720,000	bytes
9		Kilobytes	720	kilobytes
10		Megabytes	0.72	megabytes

1. Enter the width in inches of the image to be scanned.
2. Enter the depth or height of the image be scanned.
3. Enter the screen's resolution in dots per inch (dpi). This is normally 72 dpi on average.
4. Enter the desired width of the image in pixels.
5. The vertical size of the image is calculated by dividing it's width on line 4 by the ratio of the original's width to height calculate by dividing line 1 by line 2.

6. Enter the color depth of the image. This would usually be 1 if the image is black & while, 8 if it's grayscale (like a black and white photography), or 24 if it's color.
7. The file size in bits is calculated by multiplying the horizontal by the vertical size of the original (lines 4 and 5) to calculate the total number of pixels in the image and then multiplying those by the color depth (line 6).
8. The file size in bytes is calculated by dividing the file size in bits (line 7) by 8.
9. The file size in kilobytes is calculated by dividing the file size in bytes (line 8) by 1,000.
10. The file size in megabytes is calculated by dividing the file size in kilobytes (line 9) by 1,000.